W71-10653

CLEAN WATER
WATER POLLUTION CONTROL RESEARCH SERIES • 15080EUU 10/70

PB 201 656

VORTEX SEPARATION FOR OIL SPILL RECOVERY SYSTEMS

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

ENVIRONMENTAL PROTECTION AGENCY • WATER QUALITY OFFICE

1 Accession Number: W 71-10653

2 Subject Field & Group: 05G, 05D

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 Organization

American Process Equipment Corporation, Panama City, Florida

6 Title

VORTEX SEPARATION FOR OIL SPILL RECOVERY SYSTEMS,

10 Author(s)

~~None~~

16 Project Designation: EPA Program 15080 EUU 10/70

21 Note: Copy available from GPO Sup Doc, $0.60 in ~~paper~~ copy; microfiche from NTIS as PB 201 656, $0.95.

22 Citation

Water Pollution Control Research Series, ~~15080 EUU 10/70, 54 pages~~ October 1970, 54p, 10 fig, 4 tab, 3 ref, 7 append

23 Descriptors (Starred First)

*Oil-water interfaces, *Separation techniques, *Vortices, Oily water, Pollution abatement, Design criteria, Analytical techniques, Specifications, *Skimming, Storage, Mixing, Suspension, Quality control, Water purification, Water pollution control, Waste water treatment, Oil wastes,

25 Identifiers (Starred First)

Oil spills, Sweeping, *Vortex separation process,

27 Abstract

In recent years the subject of oil spills, such as resulted in the cases of the Torrey Canyon and the Santa Barbara Channel as well as numerous minor accidents during the last few years, has become of increased public interest. The demand for quick, effective solutions to the problem has brought about extensive programs for the development of equipment and technology for the safe, fast and efficient recovery of spilled oils from water. Research was begun to develop a full scale prototype oil/water separator, potentially capable of filling the need for a continuous, rapid, efficient oil/water separator, operable in choppy to moderately heavy seas, and capable of separating low concentration oil/water mixtures into recovered oil nearly free of water and clear water suitable for return to sea. The result of the research showed that a simple vortex separation process is an efficient method of separating and can rightfully be incorporated into a total oil recovery system comprising sweeping-skimming-separation-storage. Better than 99.5% of influent oil was recovered from mixtures with water of 1-10% oil. Recovery of 90% was obtained with influents containing only 0.1% oil. Effluent quality in the range of 100 to 200 ppm was reproducibly achieved. A functional gimbal stand and flexible hose connections were used in the full-scale portotype demonstrations. (Adkins-Texas)

Abstractor: Katherine Adkins | Institution: Texas Univ, Austin

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Reports describe the results and progress in the control and abatement of pollution in our Nation's waters. They provide a central source of information on the research, development, and demonstration activities in the Water Quality Office of the Environmental Protection Agency, through inhouse research and grants and contracts with Federal, State and local agencies, research institutions, and industrial organizations.

Inquiries pertaining to Water Pollution Control Research Reports should be directed to the Head, Project Reports System, Planning and Resources Office, Office of Research and Development, Water Quality Office, Environmental Protection Agency, Room 1108, Washington, D. C. 20242.

VORTEX SEPARATION PROCESS FOR OIL SPILL RECOVERY SYSTEMS

By

AMERICAN PROCESS EQUIPMENT CORPORATION
2015 Lisenby Avenue
Panama City, Florida 32401

for the

WATER QUALITY OFFICE

ENVIRONMENTAL PROTECTION AGENCY

Program No. 15080 EUU

October, 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 60 cents

EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

A two-phase program to design, fabricate, and test a 1 MGD prototype oil/water separator for use in oil spill recovery systems was completed successfully. In Phase I, an experimental 50 GPM vortex separator was built and tested in a variety of operating modes, leading to definition of a preferred vortex separation process.

The Phase II full-scale prototype was tested at a Standard Oil Company refinery. Oil/water mixtures containing from 1 - 10% oil were successfully separated to yield water effluents containing 65 - 235 ppm total oil. Recovered oil contained 1 - 5% water. Recovery of influent oil from the mixture exceeded 99.5% under reproducible operating conditions.

Operation and performance of the full-scale prototype duplicated those of the 50 GPM experimental model. The total influent capacity of the prototype was about 50% of the project objective of 1 MGD, due to use of theoretically derived scaling laws which were subsequently shown to be inapplicable to the preferred process defined.

The preferred vortex separation process uses a combination of centrifugal force and the force of gravity to facilitate oil recovery by causing floating oil to collect in a "submerged oil vortex" from which it can be removed by pumping. The submerged oil vortex acts as an oil surge tank, eliminating the need for precise control of rate of oil removal in response to variable influent oil rates. The process efficiency, in common with that of other proposed oil separation processes, varied inversely with the extent of emulsification or dispersion of oil in water, and directly with the concentration of oil in the influent mixture.

This report was submitted in fulfillment of Contract No. 14-12-825 between the Federal Water Quality Administration and American Process Equipment Corporation.

Key Words: Vortex separation, submerged oil vortex, separator efficiency.

CONTENTS

Section		Page
	Abstract	i
	Contents	ii
	List of Figures	iii
	List of Tables	iv
I	Conclusions	1
II	Recommendations	3
III	Introduction	4
IV	Phase I. Vortex Separation Process Development	6
V	Phase II. Design and Construction	24
VI	Phase II. Full-Scale Prototype Demonstration and Evaluation	30
VII	Discussion	33
VIII	Acknowledgements	36
IX	References	37
X	Patents and Publications	38
XI	Glossary	39
XII	Appendices	40

FIGURES

		Page
I	Deep Vortex Skimming Process	7
II	Shallow Vortex Overflow Process	10
III	Formation of "Submerged Oil Vortex"	13
IV	Gravity Flow Oil Recovery from Submerged Oil Vortex	15
V	Upward Vertical Suction Oil Recovery from Submerged Oil Vortex	17
VI	Phase I (50 GPM) Vortex Separator	18
VII	Phase I Experimental Vortex Separator System	19
VIII	Phase II Vortex Separator Test Installation at Refinery	26
IX	Phase II Full-Scale Prototype Vortex Separator Top View	28
X	Phase II Full-Scale Prototype Vortex Separator Side View	29

TABLES

No.		Page
1	Selected Vortex Separator Process Development Tests	11
2	Effect of Tilting on Submerged Oil Vortex	21
3	Effect of Oil Dispersion on Vortex Separator	23
4	Phase II Vortex Separator Oil Recovery Efficiency	32

SECTION 1

CONCLUSIONS

A simple vortex separation process has been demonstrated to be an efficient method for separating floating oils from mixtures with water. Recovery of better than 99.5% of influent oil was demonstrated from influents containing 1 - 10% oil. Recovery of 90% was obtained with influents containing only 0.1% oil. Effluent water containing as little as 10 ppm oil was obtained, and effluent quality in the range of 100-200 ppm was reproducibly achieved. Recovered oil contains 0 - 5% water.

The efficiency and simplicity of the vortex separator process and its operability over a wide range of processing variables make it favorably suited for incorporation into a total oil recovery system comprising sweeping-skimming-separation-storage.

Definition of preferred conditions for operation of the vortex separation process was achieved. The "submerged oil vortex" which forms under those conditons is a key element in the performance characteristics described herein. Critical design parameters and scaling laws for the vortex separation process equipment were defined and verified.

The vortex separation process was equally efficient with representative crude oils of specific gravity 0.82 and 0.90. Additionally, water-in-oil emulsions containing up to 30% water were effectively separated. These thixotropic emulsions with a viscosity similar to that of mayonnaise had a specific gravity of 0.93.

The vortex separation process was shown to be operable while the separator tank was being tilted up to 15 degrees from vertical. Because efficiencies and controllability are impaired by tilting, however, it is concluded that operation aboard ship should be isolated from rolling and pitching motion by gimbal mounting. A functional gimbal stand and flexible hose connections were used in the full-scale prototype demonstrations.

The submerged oil vortex feature of this separator system provides an integral oil "surge tank", obviating the need for continuous and precise matching of oil influx and withdrawal rates.

A simple pneumatic level control closed loop system was very effective in maintaining optimum operating level. Control point was an automatic water effluent valve.

The efficiency of the vortex separation process varies inversely with the degree of dispersion of oil in the water. True emulsions cannot be separated. Careful attention to minimize mixing in influent pumping and transport systems is, herefore, requisite in the overall process.

For a vortex separator of given diameter and height, separation efficiency varies inversely as the water influent flow rate, other factors being constant. This relationship determines the practical upper limit of flow capacity for a given unit.

The flow capacity of the Phase II unit is approximately 50% of the project objective of 1 MGD. Subsequent to final design of the unit, clarification of scaling laws for the submerged vortex separation process predicted this result.

SECTION II

RECOMMENDATIONS

The simple, reliable, and efficient vortex separation process defined under Contract 14 - 12 - 825 should be the subject of continuing engineering studies designed to facilitate its application in oil spill recovery and other oily pollution abatement problems. Recommended programs are:

Testing and evaluation of the Phase II separator under at-sea field conditions.

Integration of the vortex separator into a total oil spill recovery system comprising sweeping, skimming, separation, and storage.

Definition of the vortex separation process efficiencies with a wider variety of oily pollutants, including petroleum products, vegetable and animal oils, fatty acids, solvents, and greases. Process limitations with respect to oil compostions, densities, and viscosities should be determined, to permit reliable appraisal of process applicability to a wide variety of oily waste treatment problems.

Development of an automatic control loop to sense the volume of the submerged oil vortex and control oil recovery flow rate accordingly. This would assure maximum efficiency of operation and reduce required operator skill.

Design, fabrication, and evaluation of a highly portable skimmer/vortex separator system for rapid recovery of small spills in rivers, harbors, terminal docks, and other restricted waters. Such a system could be trailer-mounted for shore-based operation or adapted for use on small, maneuverable vessels.

SECTION III

INTRODUCTION

Oil spills of major proportions in recent years have resulted in widespread recognition of their ecological impact, of the urgent need to prevent such spills or to recover them rapidly if they do occur. A serious lack of existing technology and equipment for their effective recovery is also recognized. The publicity attendant to a disaster such as in the cases of the Torrey Canyon or the Santa Barbara Channel has resulted in public demand for quick, effective solutions to such problems. Industry and government officials recognize, also, that thousands of lesser oil contamination incidents occur in many natural waters annually. The summation of the damaging effects of these minor spills may indeed exceed that for the less frequent major accidents.

This Contract is a part of the Federal Water Quality Administration's extensive program to develop and provide technology and equipment for the safe, fast, and efficient recovery of spilled oils from inland and coastal waters.

A total oil spill recovery system may involve at least four basic, separate but interdependent, unit operations. They are: sweeping and/or containment; skimming; oil/water separation; and recovered oil storage. A variety of sweeping and skimming methods have been tested with varying degrees of success. Environmental conditions are always a major factor in the effectiveness of these operations.

Particularly in choppy or heavy seas, the efficiency of skimming operations may be relatively low, so that in attempting to remove oil from the water's surface, in fact a mixture of oil and water is obtained. Such mixtures often times contain only a few per cent of oil. These dilute mixtures must then be rapidly and efficiently separated into a water fraction suitable for return to sea, and an oil fraction containing a minimum of water in order to reduce interim storage requirements for recovered oil at the recovery site.

This project had as its objective the demonstration of a full-scale prototype oil/water separator, potentially capable of filling the need outlined above: a continuous, rapid, efficient oil/water separator, operable in choppy to moderately heavy seas, and capable of separating low concentration oil/water mixtures into recovered oil nearly free of water and clear water suitable for return to sea.

American Process Equipment Corporation had conceived such an oil/water separator, based on a modified hydrocyclone process. Model testing and a small prototype successfully demonstrated that the device was, qualitatively, a simple, rapid, continuous oil/water separator. This project was then authorized by Contract No. 14-12-825 "to design, fabricate, and test a 1 MGD prototype oil/water separator system". The effort was divided into two phases. Phase I comprised design, building, and testing of a 50 GPM system and a theoretical study to assist in the design of the 1 MGD prototype. Phase II comprised design, fabrication, and testing of the 1 MGD system. The project schedule and consideration of equipment and material procurement timing required that certain key features of the Phase II design be frozen prior to completion of the Phase I activity.

SECTION IV

PHASE I. VORTEX SEPARATION PROCESS DEVELOPMENT

The Statement of Work in Contract No. 14-12-825 was limited to "design, fabricate, and test a 1 MGD prototype oil/water separator system". The Period of Performance and the Estimated Cost reflected this limitation, and no process development effort was anticipated. Nonetheless, initial tests of the Phase I, 50 GPM model demonstrated that the proposed modified hydrocyclonic concept was severely limited in applicability as an oil/water separator in oil spill recovery systems. Accordingly, the Contractor undertook development studies which successfully defined a simple, effective oil/water separation process of broad applicability. This section describes the process development studies conducted on the Phase I system. Evaluation of the process is traced through four phases:

Deep vortex skimming process (original concept).

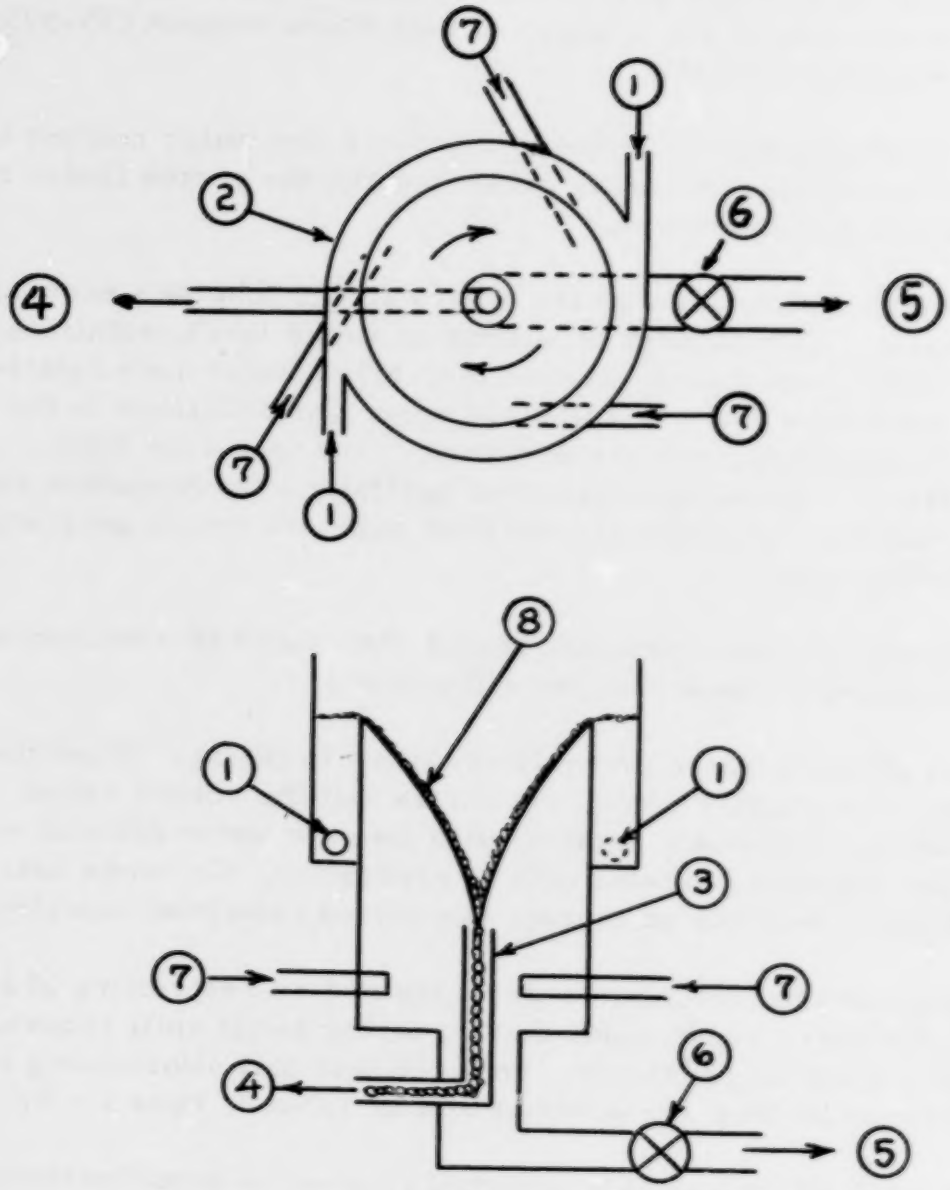
Shallow vortex overflow process.

Gravity flow oil recovery from submerged oil vortex.

Upward vertical suction oil recovery from submerged oil vortex.

The deep vortex skimming process reproduces the 2.5 GPM and 50 GPM prototype test models developed by Contractor at his expense prior to Contract No. 14-12-825. The process operates as follows (refer to Figure I.):

A mixed oil/water influent is introduced tangentially through inlet ports (1), at the bottom of an influent annular trough (2). The tangential velocity imparts a rotational motion to the mixture in the trough, filling the inner tank of the separator. Rotational speed is increased by tangential jets of recirculated water introduced through vortex generator jets (7). The rotational motion and the flow of water out the bottom through effluent pipe (5) cause formation of a deep vortex. The apex of the vortex stabilizes at a concentrically positioned vortex finder tube (3). Centrifugal force and gravity, acting on the density differential between the water and oil, cause the lighter oil (8) to seek the surface of the vortex. The oil remains at the vortex surface while flowing down to the vortex finder tube (3). The vortex finder tube then skims the oil from the vortex surface, permitting the separated oil to flow from and be recovered at (4). Water bypasses the vortex finder tube and exits through gate valve (6) at (5).



1. Influent Ports
2. Influent Annular Trough
3. Vortex Finder Tube
4. Recovered Oil
5. Water Effluent
6. Gate Valve
7. Vortex Generator Jets
8. Floating Oil

Figure I. Deep Vortex Skimming Process

Test runs of this deep vortex skimming process demonstrated the following limitations:

Recovery of a high percentage of influent oil could be achieved only at the expense of high water content (35-90%) in the recovered oil.

If skimming was controlled to achieve low water content in recovered oil, excessive oil by-passed the vortex finder tube and was not recovered.

Control of flow through the vortex finder tube was excessively erratic. This flow is dependent on liquid level, rotational velocity, vertical position of the vortex finder tube relative to the vortex apex, ripples and other perturbations in the vortex surface, and the deviation of the tank axis from vertical. These variables are partially interdependent and in turn are functions of total flow rate and vortex generator jet flow rate.

Influent oil concentrations higher than about 1% resulted in excessive oil loss with the effluent water.

The process was extremely sensitive to tilting. When the tank was slightly tilted, the vortex left the vortex finder tube and followed a vertical path into the water effluent end-pipe, resulting in total loss of separation. On more extreme tilting (5 degrees or more), the vortex collapsed completely.

These process characteristics were deemed so restrictive of applicability in oil/water separations that no utility in oil spill recovery operations could be predicted. Selected test data illustrating some of the above conclusions are summarized in Table 1, runs 1 - 5.

Experimental effort was then directed to process modifications which would ameliorate the most serious limitations of the deep vortex skimming process. The major independent variable available for study was the vortex generator jet flow rate. In tests with water only, it was shown that the depth of the vortex varied directly with that flow rate, and that a shallow vortex (depth of 2 - 4 inches compared to 18" deep vortex) formed with no vortex generator jet flow. This shallow vortex was little more than a wide, concentric depression in the rotating fluid surface. Rotation was caused by the influent flow, and thus rotational velocity was proportional to influent flow rate.

This last relationship was investigated in more detail. The Phase I unit (Figure I) has two influent ports, each of three square inch cross sectional area. It was observed that the linear tangential velocity at

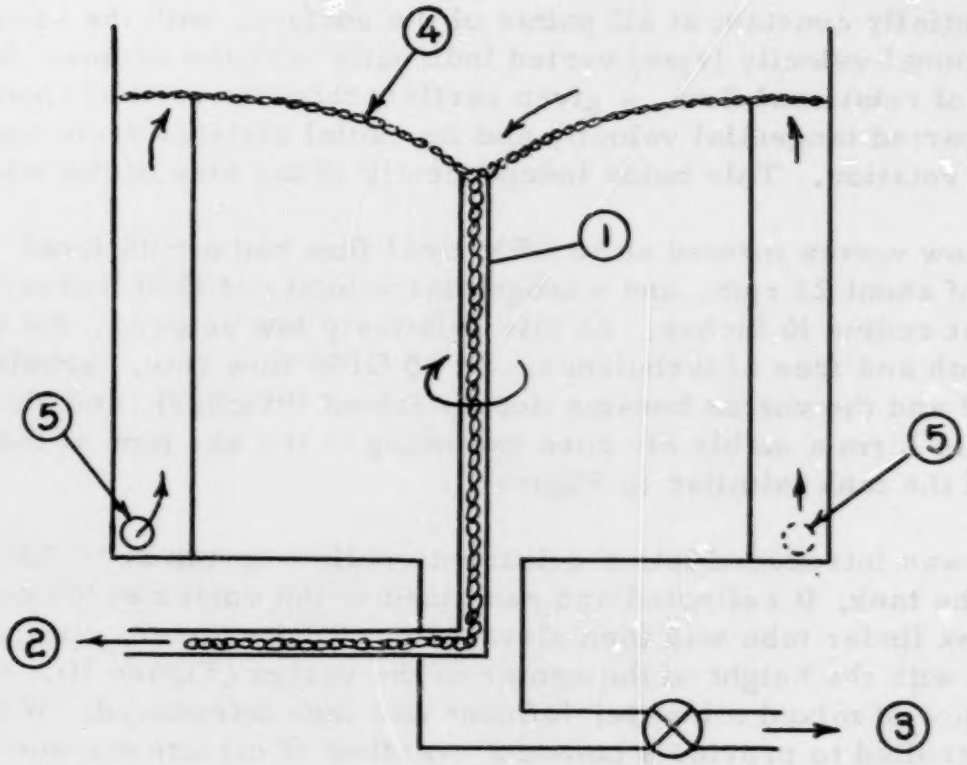
the surface of the rotating liquid approached the calculated linear velocity of flow through the influent ports, over a range of total flow rates from 30 to 60 GPM. Furthermore, when one of the two influent ports was blocked, directing the entire flow through one port, the surface tangential velocity approximately doubled at constant total flow. As is true of such rotating fluids, linear tangential velocity was essentially constant at all points of the surface, with the result that rotational velocity (rpm) varied indirectly with the radius. In this type of rotational flow, a given particle this moves in response to its imparted tangential velocity and its radial distance from the center of rotation. This holds independently of the size of the tank.

The shallow vortex formed at 50 GPM total flow had a rotational velocity of about 22 rpm, and a tangential velocity of 1500 inches/minutes at radius 10 inches. At this relatively low velocity, the surface was smooth and free of turbulence. At 60 GPM flow rate, turbulence increased and the vortex became deeper (about 10inches), and showed a tendency to form a stable air core extending to the end pipe at the bottom of the tank (similar to Figure I).

When oil was introduced into a quiescent shallow vortex at 50 GPM flow through the tank, it collected and remained in the vortex at the center. The vortex finder tube was then elevated so that its upper, open end was even with the height of the center of the vortex (Figure II). A continuous flow of mixed oil/water influent was then introduced. With level controlled to provide a constant overflow of oil into the vortex finder tube, effective separation was achieved. This was called the shallow vortex overflow process.

The shallow vortex overflow process is an improvement over the deep vortex skimming process, and has applicability for separation of oil/water mixtures under ideal conditions (constant flow rates and influent composition). However, it also has limitations which would limit its applicability in oil spill recovery systems where ideal conditions cannot be anticipated. The key characteristics are:

> Oil recovery rate is determined by the overflow into the vortex finder tube. The overflow in turn is controlled by the height of liquid at the center of the vortex relative to the height of the vortex finder tube. For a fixed tube position, the controlling variables are total flow rate and liquid level in the tank.
>
> Assuming constant total flow rate and precise liquid level control, constant overflow oil recovery is possible. On the other, if oil influent rate is variable (as it would be under field conditions), recovered oil has a variable and uncontrollable water content, and/or at high oil flows, only partial recovery is achieved.



① Vortex Finder Tube

② Recovered Oil

③ Water Effluent

④ Floating Oil

⑤ Influent Ports

Figure II. Shallow Vortex Overflow Process

TABLE 1. SELECTED VORTEX SEPARATOR PROCESS DEVELOPMENT TESTS

RUN NO.	INFLUENT, GPM WATER	OIL	% OIL	RECOVERED OIL FLOW, GPM	RECOVERED OIL, % WATER	% OF INFLUENT OIL RECOVERED	COMMENT
1	50	0.25	0.5	2.0	90	80	10 GPM Recirculation, deep vortex skimming.
2	40	1.0	2.5	1.0	5	95	35 " " " " "
3	40	1.0	2.5	1.5	35	97	35 " " " " "
4	45	0.7	1.5	0.25	0	36	15 " " " " "
5	45	0.7	1.5	1.5	55	96	15 " " " " "
6	50	4.2	8.5	4.0	4	91	No recirculation. Shallow overflow vortex.
7	37	3.7	10.0	3.5	20	75	" " " " "
8	50	2.0	4.0	2.0	4	96	" " " " "
9	50	1.0	2.0	1.0	30	70	" " " " "
10	50	2.0	4.0	2.0	20	80	" " " " "
11	40	0.1	0.25	0.15	35	97	" " " " "
12	45	0.5	1.1	0.5	2-	98+	Submerged vortex tube, gravity recovery.
13	45	0.5	1.1	0.5	2-	98+	" " " " "
14	30	0.5	1.7	0.6+	10	98+	" " " " "
15	40	3.0	7.5	3.0+	5	98+	" " " " "
16	40	0.05	0.1	0.05	10	90	" " " intermittent recovery.
17	40	0.5	1.1	0.5	2-	98+	Vertical upward suction oil recovery.
18	50	3.0	6.0	3.5	5	98+	" " " " "
19	50	6.0	12.0	6.0	2-	98+	" " " " "

A control system to sense influent composition and total flow rate and adjust vortex finder tube position continuously to provide variable oil recovery rate in response to variable oil influent rate is feasible. However, such a system would be complex and expensive.

Selected data illustrating these characteristics of the shallow vortex overflow process are shown in Table 1, runs 6 - 10.

In the course of experimentation with the shallow vortex overflow process, it was observed that at times a pool of oil formed and remained around the vortex finder tube. At such times, the composition of recovered oil approached 100% oil. The pool could be eliminated by raising the liquid level to increase the oil recovery flow rate, so that recovery rate exceeded influent rate. This observation led to a hypothesis, which was confirmed by experiment.

The hypothesis assumed that in a rotating oil/water mixture, floating oil would migrate to and remain in a "pocket" at the surface and center of the liquid. A simple laboratory test was run to test the hypothesis. About 750 ml of a 5% oil/water mixture was placed in a one liter glass beaker, and allowed to stand at rest. Of course, the oil floated in a uniform layer on top of the water. A magnetic stirring bar was added, and the mixture was stirred slowly. The oil immediately moved to the center of rotation, and formed a largely submerged pocket of oil. The photographs in Figure III show clearly what happened . It was further demonstrated that the diameter of the "submerged oil vortex" decreased and the depth accordingly increased as the rotational speed was increased. The submerged oil vortex forms as a result of the minor centrifugal force present acting on the density differential between the oil and the water.

It was reasoned that the submerged oil vortex could be utilized as a reservoir from which to recover nearly water-free oil. The Phase I vortex separator was further modified to test this concept.

The modified setup is shown schematically in Figure IV. The vortex-finder tube was lowered so that its open end was three inches below the surface of the shallow vortex. An oil recovery flow control valve was installed at (3). A mixed oil /water influent was pumped to the separator at 50 GPM, and liquid level control was established by manual setting of the valve in the water effluent line (5). No oil was removed until a submerged oil vortex of about 3 - 5 gallons was accumulated. Then the oil flow control valve (3) was regulated to maintain a submerged oil vortex of about that volume. Recovered oil flowing out at (4) contained consistently low quantities of water. The size of the submerged oil vortex was not critical as long as it was large enough to surround the open

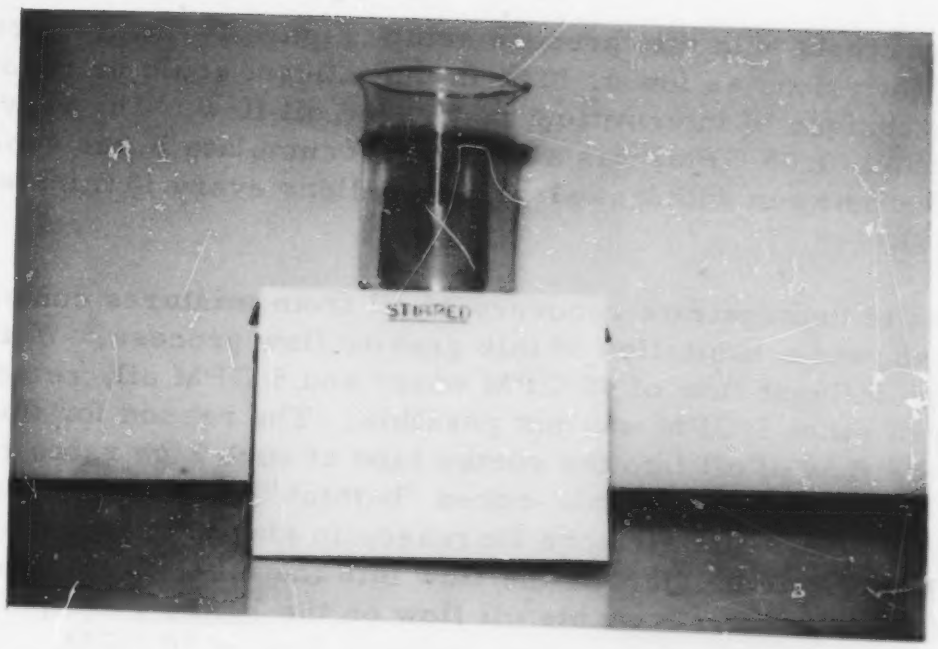


Figure III. Formation of "Submerged Oil Vortex"

end of the vortex finder tube with a pocket of oil. In fact, oil recovery could be stopped to permit the submerged oil volume to increase, and then oil could be withdrawn rapidly until the pocket was so small that entrained water appeared in the recovered oil.

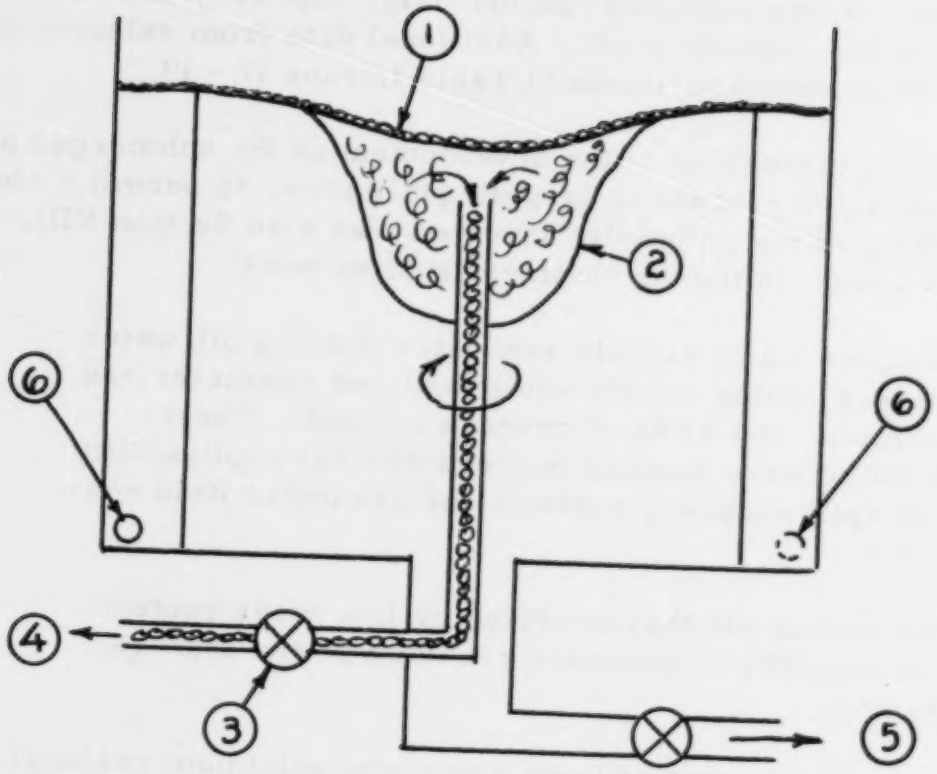
Obviously, this process eliminates some of the severe control limitations noted for the deep vortex skimming process and the shallow vortex overflow process. The improvement essentially stems from the fact that the two earlier processes require plug flow of oil through the system, in turn requiring constant control of oil recovery flow in response to variable oil influx rate. The submerged oil vortex comprises an oil "surge chamber", which eliminates plug flow of oil through the system and, therefore, eliminates the need for constant oil recovery flow rate control.

Criticality of all process variables is reduced by this essential change. Because the physical size of the submerged oil vortex is not critical as long as the oil intake is surrounded with oil, level control is less critical. Rotational speed, which varies with total influent flow rate, is not critical. This system is also markedly less sensitive to tilting (to be discussed in more detail later). Data illustrating the performance capability of the gravity flow oil recovery from submerged oil vortex process are shown in Table I, runs 12 - 16.

Additional tests with this process setup (Figure IV) demonstrated that oil concentrations as low as 0.1% in the influent could be recovered, by the technique of intermittent recovered oil flow. The very low rate of oil influx (0.05 GPM) was allowed to accumulate in the submerged oil vortex between withdrawals of 0.5 gallons every 10 minutes (Table I, run 16).

Attempts to demonstrate recovery of oil from mixtures containing 10% oil showed a limitation of this gravity flow process. While introducing an influent flow of 45 GPM water and 5 GPM oil, removal of recovered oil at 5 GPM was not possible. The reason for this limitation is that the flow of oil into the vortex tube at such high rates resulted in formation of a normal, air-cored "bathtub" vortex, feeding into the vortex tube. The air core increases in size with increasing flow rate, and effectively starves the flow into the tube. Tests showed the upper limit of recoverable oil flow on the Phase I equipment to be about 3 GPM, or 6% oil in a total influent flow of 50 GPM.

One additional modification was made to eliminate this limit on the oil concentration range. The vortex tube was removed, and in its place, a vertical upward suction oil recovery tube was installed. Refer to Figure V. The oil suction intake (3) comprised a bell immersed in the submerged oil vortex (2). The bell was connected



1. Floating Oil
2. Submerged Oil Vortex
3. Oil Flow Control Valve
4. Recovered Oil
5. Water Effluent
6. Influent Ports

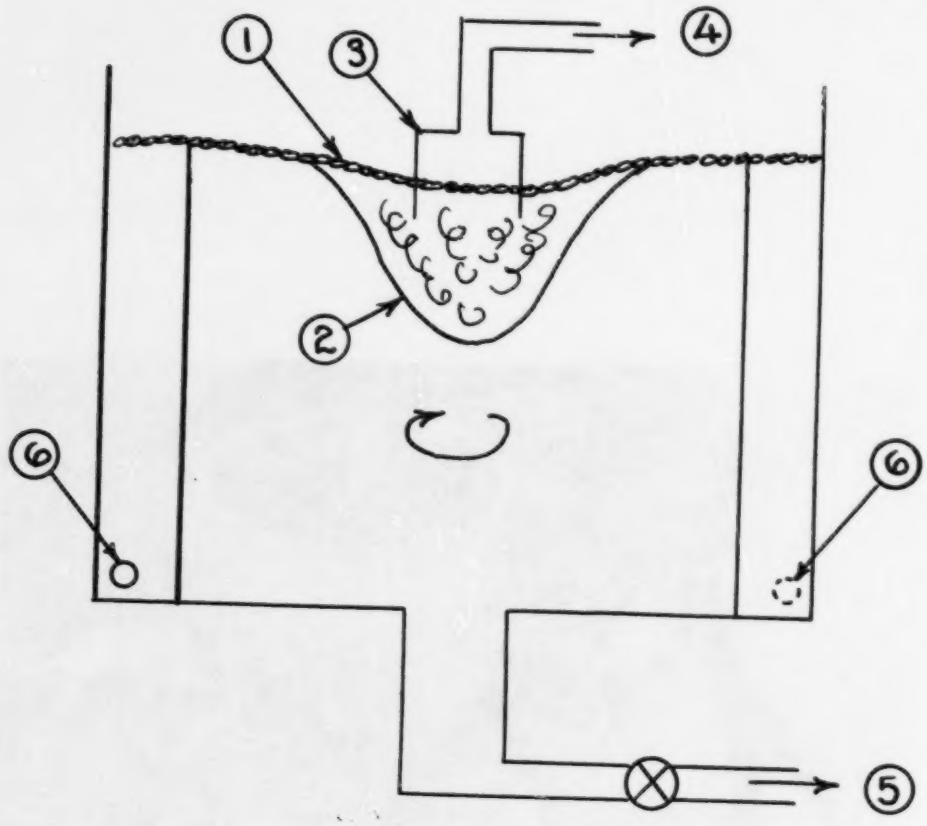
Figure IV. Gravity Flow Oil Recovery From Submerged Oil Vortex

by piping (4) to an oil recovery pump. This configuration eliminated the formation of an air-cored vortex at high oil flow rates, while retaining all the favorable attributes of the submerged oil vortex process. Recovery of as high as 7.5 GPM of oil from a 50 GPM, 15% oil influent was achieved continuously, with very low (less than 2%) water in the recovered oil. Additional data from selected runs in this configuration are shown in Table I, runs 17 - 19.

The foregoing discussion of the development of the submerged oil vortex separation process is largely qualitative, to permit a clear understanding of the principles involved (See also Section VII). The objectives sought in the development studies were:

> A process which rapidly separates floating oil/water mixtures, using simple equipment and characterized by simple, non-critical process control. These attributes were deemed prerequisite for applicability in oil spill recovery systems for use under field conditions.
>
> A recovered oil characterized by low water content (less than 5%) to minimize required at sea storage capacity.
>
> A separated water effluent containing minimum residual oil, suitable for direct return to sea without further treatment or storage.

Progress toward and achievement of the first two objectives are detailed in the preceeding discussions. Quantitative measurement of performance with regard to the third objective was deferred until the first two were achieved, for two reasons. First, the large number of test runs required (in excess of 150 runs were made) could not have been accomplished in the time available if quantitative analyses had been performed in each case. Secondly, it was a practical necessity with available facilities to recycle water and oil through the system from and to storage reservoirs. A constant supply of fresh water at 50 GPM was not available, and no means to dispose of large quantities of oily waste water existed. The Phase I system is shown schematically in Figure VII. An inescapable consequence of the continual recycle of water was a build-up of emulsified oil in the water supply. Consequently, quantitiative data on effluent water quality could not be obtained up to this point of the development. After the process was optimized, the entire system was cleaned and prepared for a typical run in the preferred configuration with "once through" water and oil flows. A pumper truck of clean water was provided by the Panama City Fire Department, permitting a continuous run of 30 minutes at 40 GPM.



1. Floating Oil
2. Submerged Oil Vortex
3. Oil Suction Intake
4. Oil to Recovered Oil Pump
5. Water Effluent
6. Influent Ports

Figure V. Upward Vertical Suction Oil Recovery From Submerged Oil Vortex

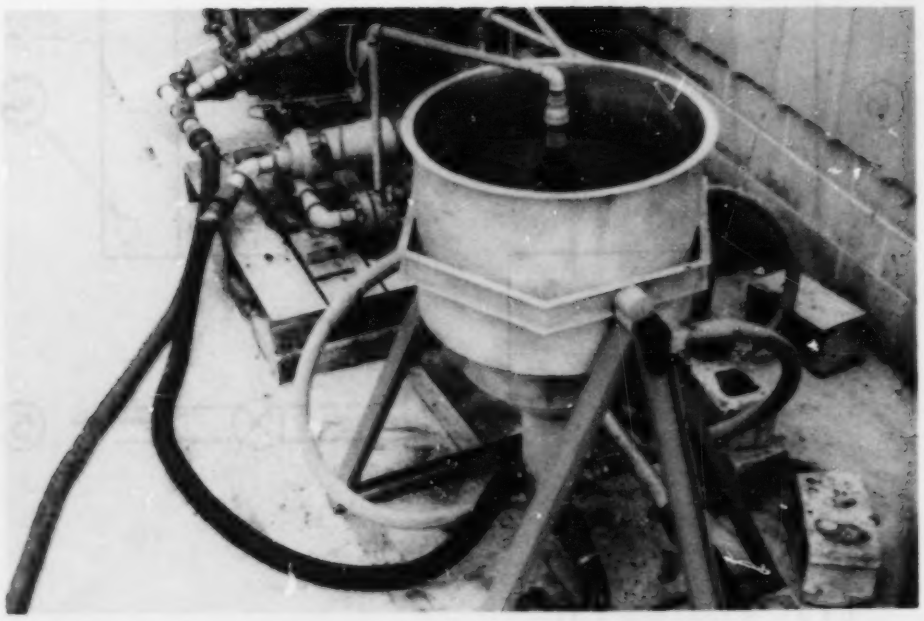
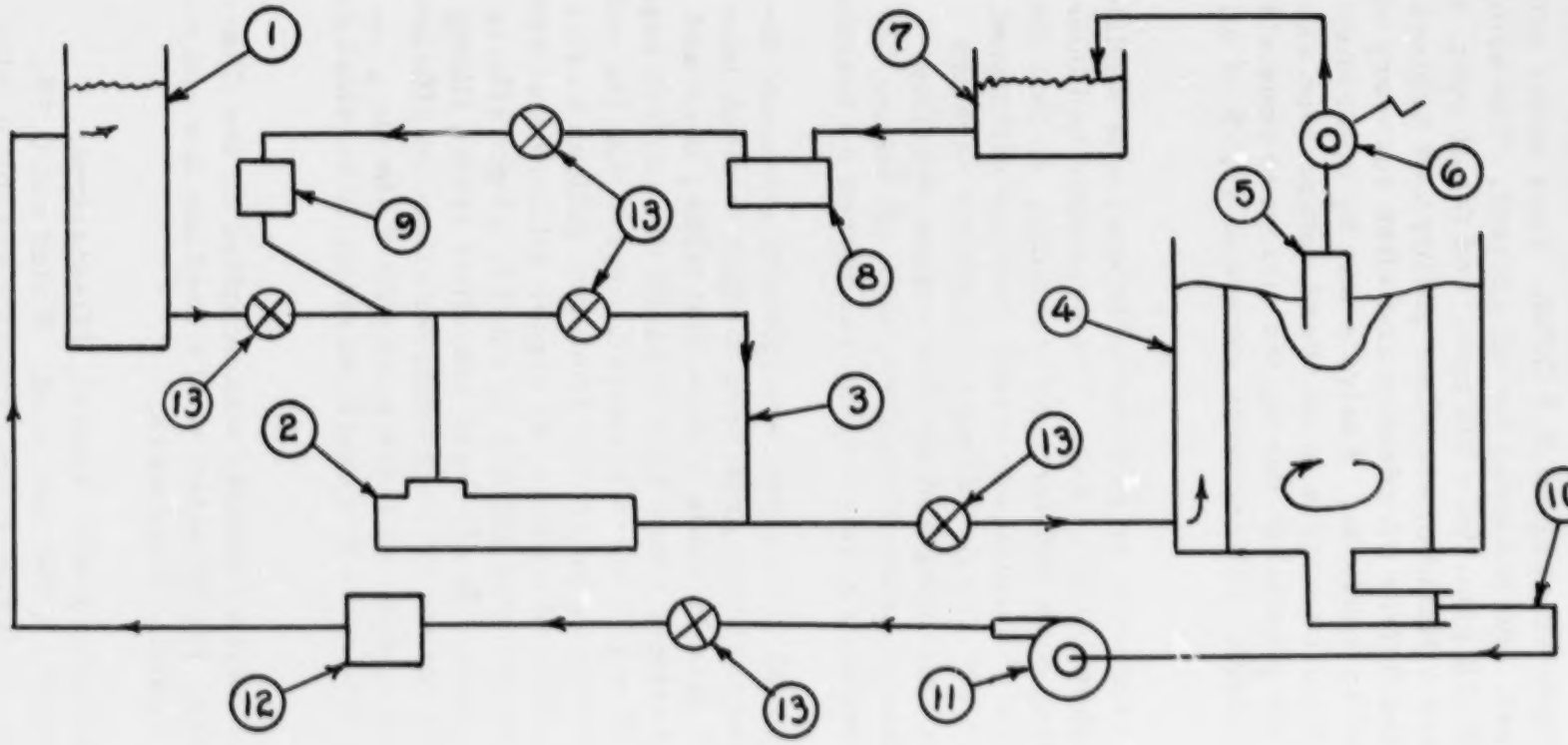


Figure VI. Phase I (50 GPM) Vortex Separator



1. Water Reservoir
2. Moyno Influent Pump
3. Pump Bypass
4. Vortex Separator
5. Oil Suction Intake
6. Oil Recovery Pump
7. Oil Reservoir
8. Oil Pump
9. Oil Flowmeter
10. Water Effluent
11. Water Return Pump
12. Water Flowmeter
13. Gate Valves

Figure VII. Phase I Experimental Vortex Separator System

An oil feed rate of 0.5 GPM (1.25%) was selected for the test, and oil was continuously recovered at about 0.5 GPM. Four water samples were taken during the test, and analyzed for oil content. The samples contained 0 - 10 ppm, 10 -50 ppm, 50 - 100 ppm, and 0 - 10 ppm, respectively, showing that water effluent of excellent quality was achieved. Control samples collected before oil addition and after recovery of all the oil had 0 - 10 ppm oil by analysis. Analysis was by colorimetric matching of trichloroethylene extracts to standard comparison samples (See Appendix E). Oil samples taken during the run were consistently less than 5% in water content. Oil recovery exceeded 99.6% of oil influent.

The effect of tilting the separator on process efficiency was studied, to permit prediction of operability at sea. The separator had been designed to permit rocking back and forth on trunnions, so that the effect of wave motion on a shipboard separator could be estimated. It was quickly shown that even slight tilting had a major negative effect on the deep vortex skimming and shallow vortex overflow processes. Complete loss of control resulted, with oil losses to the water effluent, and excessive water in the recovered oil fraction.

Tests with the submerged oil vortex process (gravity recovery through a submerged tube) showed that this preferred method is much less sensitive to tilting. The data in Table 2 show that tilting back and forth 7.5 degrees from vertical every four seconds does affect separation efficiency. Run #1 and #2 were identical, except that the volume of oil in the submerged oil vortex was increased from two gallons to five gallons, largely overcoming the effect of tilting. At higher oil flow and with a submerged oil vortex volume of three gallons in run #3, slight effects of tilting 7.5 degrees were seen. In all these and other tests, tilting 15 degrees from vertical did have a serious negative effect on efficiency. Accordingly, the Phase II system was designed with a simple gimbal support stand to permit the separator to remain essentially vertical despite ship's motion.

The crude oil used in the Phase I studies was supplied by the Chevron Oil Company. Two grades, representative of a medium low and medium high density crude, were used. They were:

Sample #1: Reedy Creek Field, Laurel, Mississippi.
Well depth 11,400 feet sand. Water cut 0.3%.
Gravity 25 degrees API (specific gravity 0.905).

Sample #2: Raleigh Field, Raleigh, Mississippi.
Well depth 11,750 feet sand. Water cut 0.4%.
Gravity 41.1 degrees API (specific gravity 0.820).

TABLE 2. EFFECT OF TILTING ON SUBMERGED OIL VORTEX SEPARATION PROCESS

		Water Influent	Oil Influent	% Water in Oil Effluent	Tilting
1.	a.	45 GPM	0.5 GPM	2	None
	b.	45	0.5	59	7.5° back and forth
	c.	45	0.5	81	15° one way
2.	a.	45	0.5	2	None
	b.	45	0.5	2	7.5° back and forth
	c.	45	0.5	80	15° one way
3.	a.	40	3.0	5	None
	b.	40	3.0	7	7.5° back and forth
	c.	40	3.0	42	15° one way

Performance of the vortex separator over the enitre range of operating conditions investigated was not affected by the crude oil sample used. Thus, at least over the range of specific gravity 0.82 to 0.905, oil density and viscosity are not critical variables in this recovery process.

Both crude oil samples showed some propensity for formation of water-in-oil emulsions. As oil was recycled through the system during the course of experimental investigations, it increased in viscosity due to loss of volatile components and due to formation of such water-in-oil emulsions. Recovery of floating water-in-oil emulsions was repeatedly demonstrated with the submerged oil vortex process, again over the full operating range discussed in this section. Recovery efficiency of a thixotropic, viscous emulsion of composition 70% Sample #1 crude oil and 30% water was identical to that of fresh crude oil. The emulsion had the consistency of mayonnaise and a specific gravity of 0.93. The single operating variable affected was, of course, power required to pump the recovered emulsion. For this reason, the oil recovery pump should be a positive displacement pump adequately powered to handle a wide range of viscosities.

The vortex separator process is designed to and does recover floating oils from water/oil mixtures. It will not efficiently separate oil from permanent oil-in-water emulsions. Efficiency of recovery from temporary disperions will vary inversely with the degree of mixing or the extent of oil dispersion present in very fine droplets. Some investigations were carried out to provide semi-quantitative information on this relationship.

In each test, the Phase I separator system was thoroughly cleaned, and placed in operation with a clear water influent. Oil was then introduced by various methods which caused varying degrees of oil dispersion in the influent. The degree of dispersion was estimated by sampling mixed influent as it entered the separator. Droplet size and time required for the oil in the mixture to float completely to the surface of the sample were observed. Effluent water samples were collected and analyzed for oil content. The results are summarized in Table 3. They illustrate the importance of an ifluent transport system which will not increase the degree of dispersion of oil in water encountered at the site of a spill. Low shear, nonemulsifying pumps are required, and overall process efficiency can be improved by providing even momentary presettling so that minimum dispersed oil enters the separator. The data also show that for a given separator and influent system, efficiency varies inversely with water flow rate. This is true for all gravity separators and comprises one practical limit on the capacity of any given size vortex separator.

TABLE 3. EFFECT OF OIL DISPERSION ON VORTEX SEPARATOR EFFICIENCY

Water Influent GPM	Oil Droplet Diameter, in.	Oil Flotation Time, Min.	Water Effluent ppm Oil
1. Water and oil mixed by pumping through 1L10H Moyno pump.			
50	$\frac{1}{128}$ to $\frac{1}{64}$	50% - 1 min. 80% - 2 min. 100% - 10 min.	1000+
2. Oil added through tee in water influent hose to tank.			
50	$\frac{1}{64}$ to $\frac{1}{32}$	100% - 1 min.	500 - 1000
40	$\frac{1}{64}$ to $\frac{1}{16}$	100% - $\frac{1}{3}$ min.	250
3. Oil/water influent to tank by gravity flow in a trough.			
50	$\frac{1}{64}$	100% - 1 min.	500 - 1000
4. Oil added directly to water surface in influent trough.			
50	$\frac{1}{8}$ to $\frac{1}{4}$	100% - $\frac{1}{5}$ min.	35
40	$\frac{1}{8}$ to $\frac{1}{4}$	100% - $\frac{1}{5}$ min.	10 - 50

SECTION V

PHASE II FULL SCALE PROTOTYPE DESIGN, CONSTRUCTION, AND TEST FACILITIES

Design of the full-scale prototype was based on the initial Phase I experimental results and on a theoretical analysis of the deep vortex skimming process by the Contractor's sonsultant, Dr. A. B. Troesch of the University of Southern California. Unfortunately, the Contract Schedule and procurement delivery times required that key elements of the Phase II system design be frozen before process development studies under Phase I were well underway. The main consequence of this situation was that scaling factors derived in the theoretical study were used to determine major dimersions of the Phase II vortex separator. Later studies which elucidated a different and preferred vortex separation process also showed that different scaling factors apply (see p. 43). As a result, the practical influent flow capacity of the Phase II system is about 50% of the Contract objective of 1 MGD.

The Phase II vortex separator inner tank was built with diameter 60 inches and height 31 inches. Our present knowledge of the submerged oil vortex separation process suggests that the corresponding dimensions for a 1 MGD separator should be 75 inches and 65 inches, respectively. Influent degree of mixing was recognized as a critical factor in overall separator efficiency. An effort to reduce the amount of dispersed oil entering the tank was made by introducing the influent flow into a plenum chamber underlying the separator tank itself. Flow was then directed tangentially out of the plenum and into the influent annular trough surrounding the separation tank. This design provided both time (10 - 20 sec) and metal surface contact to permit coalescence of fine droplets into larger drops which would float and be separated more readily.

The Phase I tests showed that the vortex separator does function even when tilted from vertical. However, reliability, control, and efficiency are reduced under such conditions. Accordingly, the Phase II unit was designed for support on a gimbal stand. It is thus isolated from pitching and rolling motion and can be tested at sea on its present mounting. Flexible hose connections were also provided to permit relative motion between the tank and fixed pumps on shipboard.

The Phase II tank was of welded construction, fabricated from 6061-TG aluminum. The tank and the gimbal support stand were fabricated for the Contractor by Metric Systems, Inc., Fort Walton Beach, Florida.

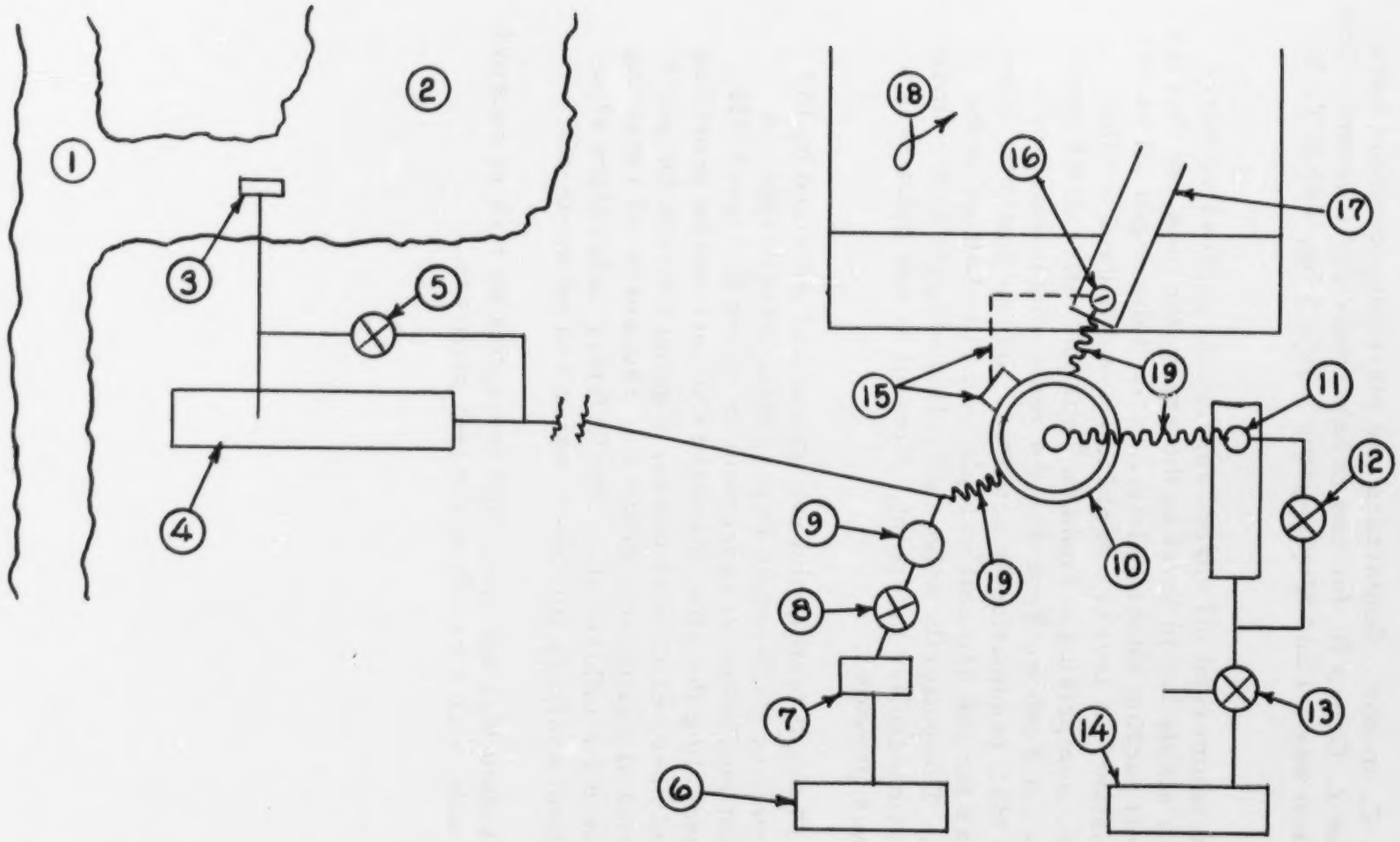
The influent pump for the Phase II system was an SWG88 Moyno pump manufactured by Robbins and Myers. It was powered by a 25 hp,

440 V T. E. F. C. motor. Contactors and start-stop controls were Class I, Division 2, Group D, for use in hazardous environment. The oil recovery pump was a 1 L10 Moyno pump with a 5 hp, 440 V T. E. F. C. motor.

Operation of the submerged oil vortex separation process requires maintenance of a stable liquid level in the separator tank, so that the position of the oil suction intake relative to the submerged oil vortex will remain constant. A level control loop was designed for the Phase II system, comprising a Foxboro Type 13A differential pressure cell sensor, a Foxboro Type 43A A4 reset controller, and a Foxboro Model M3L pneumatically actuated 6 inches butterfly valve. The pressure tap for the d/p cell was placed at the bottom of the separator tank. The butterfly valve controlled effluent flow to maintain tank level at controller set-point. Control at any point over a 20 inch range was provided.

A test site for Phase II testing and evaluation was provided by the Standard Oil Company Refinery at Pascagoula, Mississippi. A sketch of the test equipment arrangement is shown in Figure VIII. In addition to providing the site, Standard Oil assisted by providing water piping and hose, electrical power, rigging service for placement and removal of equipment, crude oil, recovered oil receiving tanks, and a pump for influent oil. The Refinery Laboratory also performed effluent analyses for oil-in-water and water-in-oil.

The Phase II system was set up so that there was no risk of contaminating natural waters as a result of the test program.



See key, opposite page.

Figure VIII. Phase II Vortex Separator Test Installation at Refinery

Key to Figure VIII

(1) Tidal Salt Water Canal

(2) Pond

(3) Strainer Intake

(4) Moyno SWG88 Influent Pump

(5) Pump Bypass

(6) Oil Supply (by Refinery)

(7) Oil Pump (by Refinery)

(8) Gate Valve Control

(9) Oil Flowmeter

(10) Vortex Separator

(11) Oil Recovery Pump

(12) Pump Bypass

(13) Sample Tap

(14) Recovered Oil Tank (by Refinery)

(15) Level Control System

(16) Automatic Butterfly Valve

(17) Water Effluent Trough

(18) A.P.I. Separator (Refinery)

(19) Flexible Hose

Figure IX. Phase II Full Scale Prototype Vortex Separator
Top View

Figure X. Phase II Full Scale Prototype Vortex Separator
Side View

SECTION VI

PHASE II. FULL-SCALE PROTOTYPE VORTEX SEPARATOR PROCESS DEMONSTRATION AND EVALUATION

The Test installation is shown schematically in Figure VIII.

Salt water influent from a tidal canal was supplied to the SWG88 Moyno influent pump through a strainer intake. A manually controlled butterfly valve in the bypass piping from pump discharge to intake was used to control net discharge flow to the separator. The separator was located about 200 feet from the influent pump, at the end of an A. P. I. separator.

Oil was injected into the influent water stream through a tee in the line 15 feet ahead of the separator. Oil flow was controlled by a manual gate valve and measured by a Foxboro d/p cell and orifice plate flow-meter. The crude oil was supplied by tank truck by the Refinery, and pumped by a centrifugal oil pump furnished by the Refinery.

Recovered oil was pumped out of the submerged oil vortex by the 1L10 Moyno pump. Net oil recovery rate was controlled by a manually operated plug valve in the bypass piping on the pump.

After all equipment had been installed and checked out for proper functionality, a period of qualitative testing was undertaken to establish optimum operating conditions.

At full influent pump output of 700 GPM (1 MGD), excessive rotational velocity in the separator tank resulted in formation of a deep vortex, and no recovery of oil was possible (see discussion of scaling factors, Section VII, p. 43). The influent flow was reduced stepwise until a controllable and stable submerged oil vortex could be generated. This occurred at a flow of 300 - 325 GPM. Application of the proper scaling relationship between diameters and optimum flows in phase I and Phase II equipment gave a calculated capacity of 360 GPM. The experimental optimum was less because the tank depth was also improperly scaled. It is the Contractor's opinion that the Phase II unit capacity can be increased to 360 GPM or slightly more, by increasing the tank depth by about 30 inches.

Additional tests were run to establish the preferred liquid level and positioning of the oil recovery suction intake. Liquid level was established at 0.5 inches below the top edge of the inner tank. The preferred position of the bottom of the suction intake was 4 inches below the liquid level.

The flow in the influent trough was of substantially lower linear velocity than in the Phase I system (approx. 200 inches per min compared to 1200 - 1500 inches per min). This resulted from a combination of two factors. First, inlets were designed to provide the desired velocity at 700 GPM, and the system was operable at only half that rate. Secondly, the design of the baffles directing influent flow from the plenum tangentially into the influent trough was inadequate. Because these baffles were too short, the flow was actually about 30 degrees from the desired tangential direction. This resulted in dissipation of tangential velocity in the influent trough.

With the exception of the total capacity and influent baffles discussed above, the entire vortex separator system performed according to designed objectives. The operation was exactly as expected from that in the smaller Phase I unit.

A series of quantitiative tests was then undertaken to provide reliable data on the efficiency of the Phase II vortex separator, operating at the preferred conditions established by the qualitative tests. As each set of test flows was set up, the system achieved stable level control and performance in 1 - 2 minutes. Stable operation was maintained for 20 - 30 minutes before samples for analysis were taken. Frequent sampling during this period permitted qualitative assurance that operation was stable and that the analytical samples were representative of the separator's performance. Data are summarized in Table 4. Data describing the crude oil and the salt water used in these tests are included in the Appendix G, and were furnished by Standard Oil. Test Numbers 3, 4, and 5 were witnessed by the Project Officer.

TABLE 4. PHASE II VORTEX SEPARATOR OIL RECOVERY EFFICIENCY

TEST NO.	1	2	3	4	5
% Oil Recovered[1]	97.4	96.9	99.7	99.8	99.9
Water Influent, GPM	325	250	280	280	280
Oil Influent, GPM	3	7.5	10	20	30
Total Influent, GPM	328	257.5	290	300	310
% Oil in Influent	0.9	3	3.4	6.7	9.7
Water Effluent, ppm total oil[2]	235	980	106	111	63
Recovered oil, % Water	5[3]	2[3]	0.7[2]	1.0[2]	1[3]

(1) Calculated by the materials balance equation:

$$\% \text{ Recovered} = 100 - \frac{\text{influent \% water}}{\text{influent \% oil}} \times \frac{\text{ppm oil in water effluent}}{10^4}$$

(2) Analysis by Refinery Laboratory

(3) Approximate value

SECTION VII

DISCUSSION

Analysis of all observations and tests performed in Phase I and Phase II of the project effort leads to the following general conclusions regarding the Contractor's submerged oil vortex oil/water separation process:

The oil/water vortex separation process described in this report is reproducible, simple in equipment construction and operation, and is applicable as an itegral part of sweeping-skimming-separation-storage oil recovery systems for treating oil spills in natural waters. It offers additional applicability in oil pollution control applications requiring removal of gross floating oils from large volumes of water. Such applications may include refinery waste or process waters, oily animal or vegetable waste waters, and storm runoff from such oil-laden areas as airports. Treatment of marine ballast and bilge waters may also be effective.

Work under this Contract has demonstrated that the vortex separation process can provide continuous recovery of 99.5% or more of the floating oil from an influent stream containing 5 - 15% of oil. More dilute influents down to 1% oil content can be treated to recover 99% of the oil. Efficiency as measured by percent recovery falls off with still more dilute influents, to about 90% for a 0.1% mixture of oil in water (see Appendix F).

Water effluent from the vortex separator treating an influent of floating oil and water will contain well under 200 ppm oil with proper operation. Emulsified oils or extensively dispersed oils will not be efficiently separated. Oil recovered can be controlled in composition to the range of 0 - 5% water content.

Process control comprising a simple pneumatic level control loop was demonstrated. For simplest field operations, additional instrumentation to provide automatic control of rate of oil removal from the separator is recommended.

Many of the operating characteristics of this vortex separation process are shared by other "instantaneous" oil separation process. Efficiency of such processes is highly dependent on degree of emulsification of oil in the influent and on oil concentration in the influent. This process involves simple equipment and controls, provides high space/time processing capacity, and is not significantly affected by oil densities or

viscosities over ranges most commonly encountered.

A simple influent plenum chamber to facilitate oil droplet coalescence and thus improve efficiency by reducing oil dispersion was effective. This result can logically be extended to larger pre-coalescence tanks to provide further improved efficiencies.

A gimbal support stand for the vortex separator tank serves to isolate the separator process from pitching and rolling motion at sea, thus overcoming undesirable effects of excessive tilting on separator performance.

The submerged oil vortex separation process has been adequately defined to permit reliable design and operation of units ranging from 50 GPM to 1000 GPM in nominal influent capacity.

The vortex separation process equipment has no moving parts and no power requirements except the pumps for supplying influent and removing oil to storage. Water effluent may be discharged by pumps or by gravity flow. This leads to favorably low initial investment requirements and operating costs.

The simplicity of the vortex separation process equipment will facilitate development of air-transportable or air-deployable models for rapid applicability in spills anywhere within a large area. This can reduce the number of units necessary to protect the extensive inland and coastal waters of the United States.

A summary of the principles of operation and key design parameters of the submerged oil vortex separation process, as elucidated by the studies so far discussed, follows to provide a clear understanding of the simplicity and applicability of the process.

The vortex separator utilizes the force of gravity and centrifugal force operating on the density differential between oil and water. The resultant of these forces causes floating oil in an oil/water mixture to collect in a "submerged oil vortex", which forms at and below the surface of the liquid rotating in a cylindrical tank, and is coaxial with the tank. The submerged oil vortex provides a convenient pocket of oil from which oil is recovered by pumping through a vertical upward suction intake with discharge to storage. Clear water effluent

passes out a bottom pipe, coaxial with the tank, and may be returned to sea or otherwise disposed of by gravity flow or pumping.

Rotary motion of the oil/water mixture in the separator tank is generated by introducing the influent in a tangential direction through two or more inlet ports into an annular influent trough surrounding the separator tank. The rotational velocity is primarily a function of tangential velocity of the influent flow, which in turn is determined by the flow rate and the cross-sectional area of inlet ports. Flow velocities should be in the range of 1000 - 2000 inches per minute.

Flotation (gravity) provides the main separation force, while the small centrifugal force is all that is required to cause formation of the submerged oil vortex. The submerged oil vortex comprises an effective surge tank, which obviates the need for precise continuous control of oil recovery rate in response to varying oil influent rates.

Separation efficiency is dependent on rise rate of the oil droplets present in the influent mixture as compared to the vertical downflow rate of separated water through the tank. Accordingly, mixing or dispersion of oil into the water should be minimized in the influent handling system. Also, because water downflow rate is a function of the cross-sectional area of the tank, the scaling law to be used in designing tanks of various diameters, d, for various capacities, Q, is:

$$\frac{d_1^2}{d_2^2} = \frac{Q_1}{Q_2}$$

The average water downflow rate should be about 3 feet per minute to provide efficient separation of oil droplets 1/40 inch in diameter or larger. The annular influent trough increases separation efficiency because all elements of the oil/water mixture are required to closely approach the liquid surface when overflowing from the trough into the separation tank. Hence, the rise distance required for each oil droplet is minimal.

SECTION VIII

ACKNOWLEDGEMENTS

The cooperation and support of the Standard Oil Company Refinery at Pascagoula, Mississippi, Mr. Thron Riggs, Manager, was vital to our successful Phase II evaluation program. They provided a site for testing without risk of polluting natural waters, and facilitated the entire effort with support services, power, crude oil supply, and analytical services. Their assistance is gratefully acknowledged.

Metric Systems, Inc., Fort Walton Beach, Florida, fabricated both Phase I and Phase II vortex separator tanks. In addition to delivering first-class workmanship against a very demanding time schedule, their interest and constructive suggestions were of value to the Project and are sincerely acknowledged.

The City of Panama City Fire Department assisted by providing a tank truck of water for a Phase I experimental run.

SECTION IX

REFERENCES

1. Oceanology International, March, 1970, p. 18. News release describing the Seadragon oil spill recovery system being developed by the Garrett Corporation. System includes a high-speed centrifugal oil/water separator.

2. Offshore Technology, June, 1970, p. 77, News release reporting demonstration by Reynolds Submarine Services Corporation of a "Voraxial Flow" open-center pump for high-speed liquid-liquid separations.

3. Chemical and Engineering News, July 6, 1970, p. 62. News release describing a mechanically driven vortex separator for oil spill recovery, being developed by Bertin & Cie, Paris, France, for a French oil company, Elf-Erap.

SECTION X

PATENTS AND PUBLICATIONS

No publication have resulted to date from this project. Patentability of the submerged oil vortex separation process should be investigated to determine appropriate filing action.

SECTION XI

GLOSSARY

Annular influent trough - an annular trough surrounding the upper portion of a vortex separator tank. Mixed influent is introduced at appropriate velocity into the trough in a tangential direction, resulting in a rotational flow in the trough which then overflows into the separator tank.

Effluent quality - a) total oil content of water effluent expressed in ppm. b) total water content of recovered oil expressed in percent.

Moyno pumps - positive displacement, low-shear, progressive cavity pumps manufactured by Robbins and Myers, Springfield, Ohio.

Oil spill recovery system - a total system for recovery of spilled oil. A typical system would include unit operations of sweeping and/or containment; skimming; oil/water separation; and recovered oil storage.

Separator efficiency - a measure of the performance of an oil/water separator, expressed in percent Recovery of total influent oil. Efficiency is calculated from the materials balance equation:

$$\text{Percent Recovery} = 100 - \frac{\% \text{ water in influent}}{\% \text{ oil in influent}} \times \frac{\text{ppm oil in water effluent}}{10^4}$$

Submerged oil vortex - the pocket of oil which forms at and below the surface of a rotating mixture of oil and water, coaxially with the axis of rotation.

Vortex finder tube - in a vortex separator, a tube which intercepts the apex of the vortex and consequently removes components of a vortexing mixture which concentrate at the apex.

Vortex separator - a device which utilizes combined forces of gravity and centrifugal force to effect separation of a mixture into components of differing specific gravity.

SECTION XII

APPENDICES

		Page
A.	Phase I System Bill Of Materials	41
B.	Phase II System Bill Of Materials	42
C.	Phase I Separator Assembly Drawings	43
D.	Phase II Separator Assembly Drawings 1 thru 4	44
E.	Analytical Methods	48
F.	Separator Efficiency Calculations	52
G.	Phase II: Specifications of Oil and Salt Water	53

APPENDIX A

PHASE I BILL OF MATERIALS

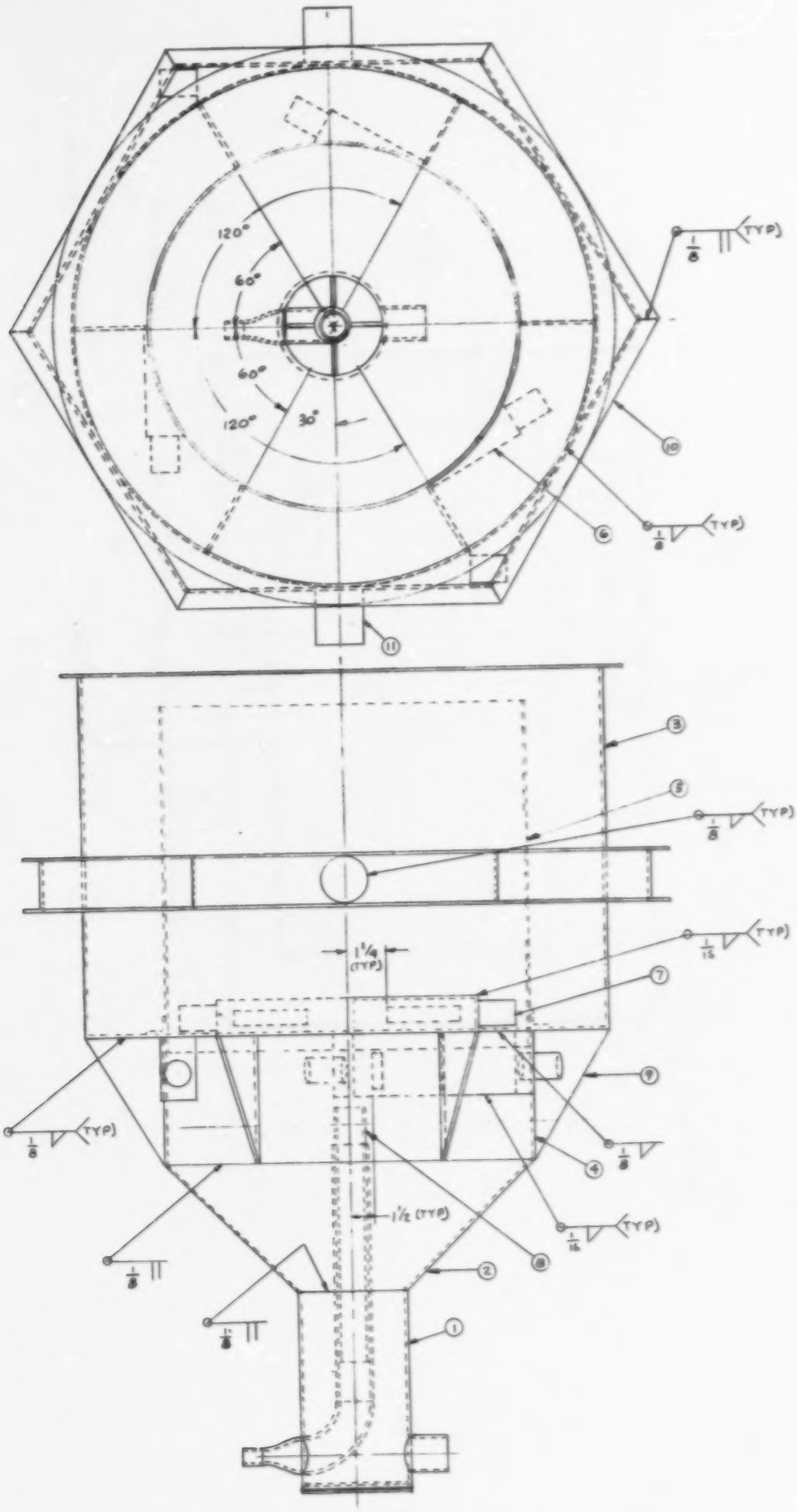
1. Welded aluminum vortex separator tank.
2. Support stand for vortex separator tank.
3. Water supply tank, 220 gallon capacity.
4. Moyno 1L10H pump with 7.5 hp motor.
5. Deming centrifugal water pump with 2 hp motor.
6. Oberdorfer Model HRCC-1 oil pump with 0.5 hp motor.
7. Electrical power contactors and motor start-stop controls.
8. Water flow meter: Foxboro 13A1 D/P cell transmitter, 2 inch threaded orifice flange union #34052, stainless steel orifice plate, Model MR receiver gauge.
9. Oil flow meter: Foxboro 13A1 D/P cell transmitter, 1 inch threaded orifice flange union #33891, stainless steel orifice plate, Model MR receiver gauge.
10. Compressed air supply to instruments, with air pressure regulator.
11. Valves, fittings, pipe, flexible hose.
12. Manual oil recovery pump.
13. Oil drum oil supply tank.

APPENDIX B

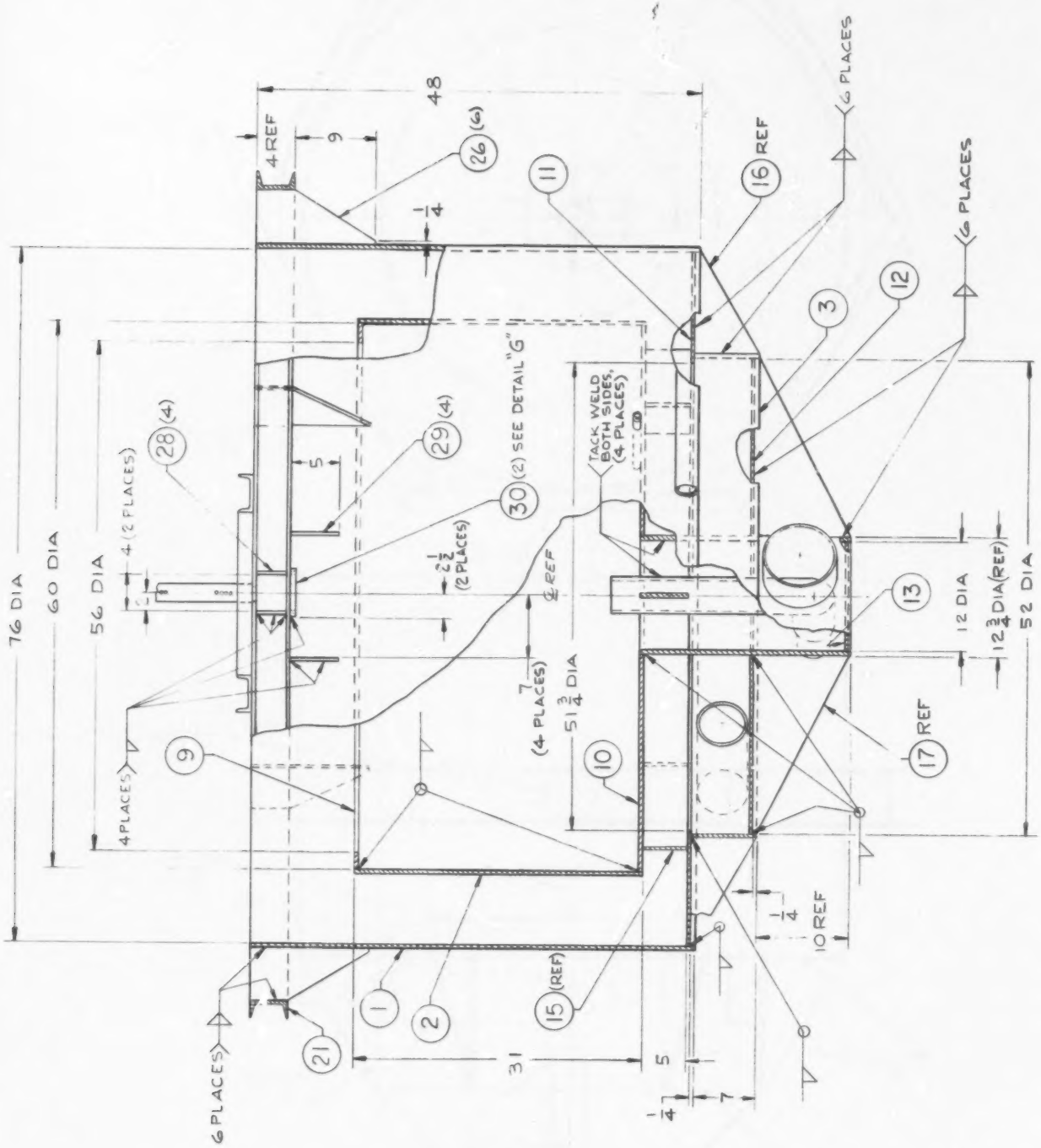
PHASE II SYSTEM BILL OF MATERIALS

1. Welded aluminum vortex separator tank.
2. Gimbal support stand for separator tank.
3. Moyno SWG88 influent pump with 25 hp, 440 V TEFC motor.
4. Moyno 1L10 oil recovery pump with 5 hp, 440 V TEFC motor.
5. Class I, Group D, Div. 2 electrical power contactors and motor starters.
6. Foxboro orifice plate and D/P celloil flowmeter (recalibrated from Phase I system).
7. Foxboro liquid level control loop, including: 13A1 D/P cell transmitter, Model 43A receiver controller, and Type M3L 6 inch butterfly control valve.
8. Screen strainer for sea water intake.
9. Compressed air for instruments, with air pressure regulators.
10. Water effluent trough.
11. Valves, pipe, fittings, flexible hose.

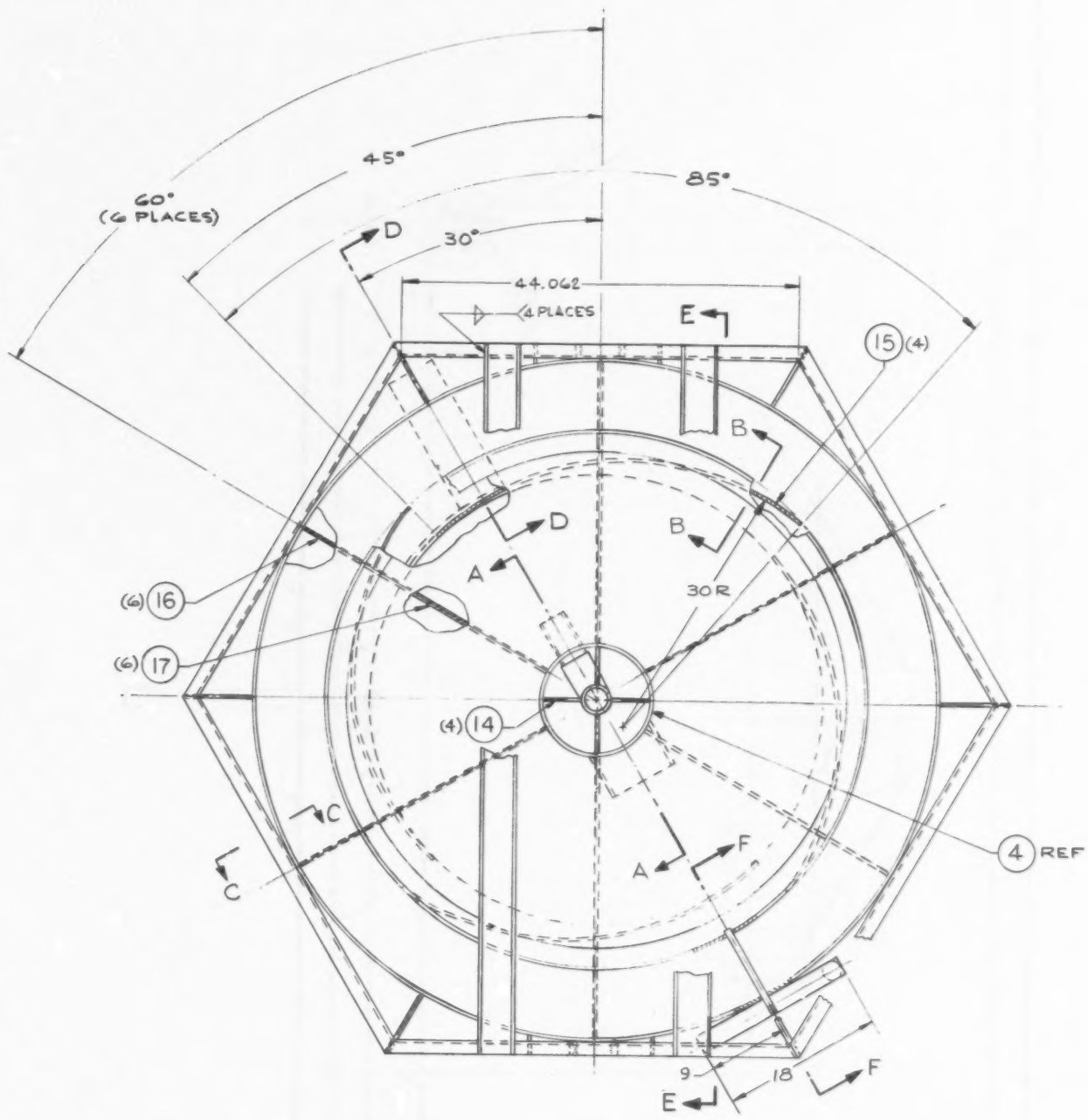
APPENDIX C. PHASE I SEPARATOR ASSEMBLY DRAWINGS



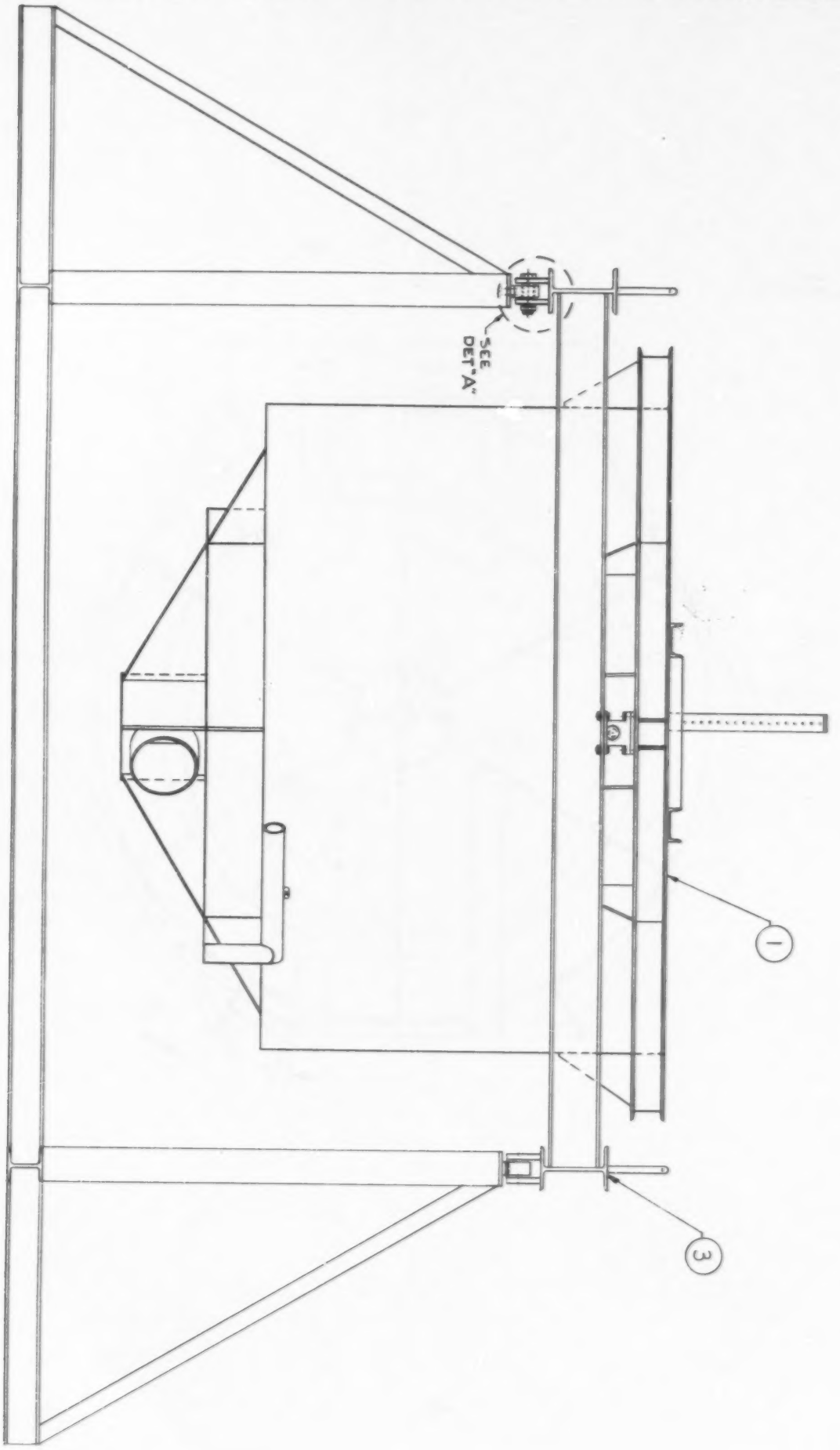
APPENDIX D. PHASE II SEPARATOR ASSEMBLY DRAWING 1



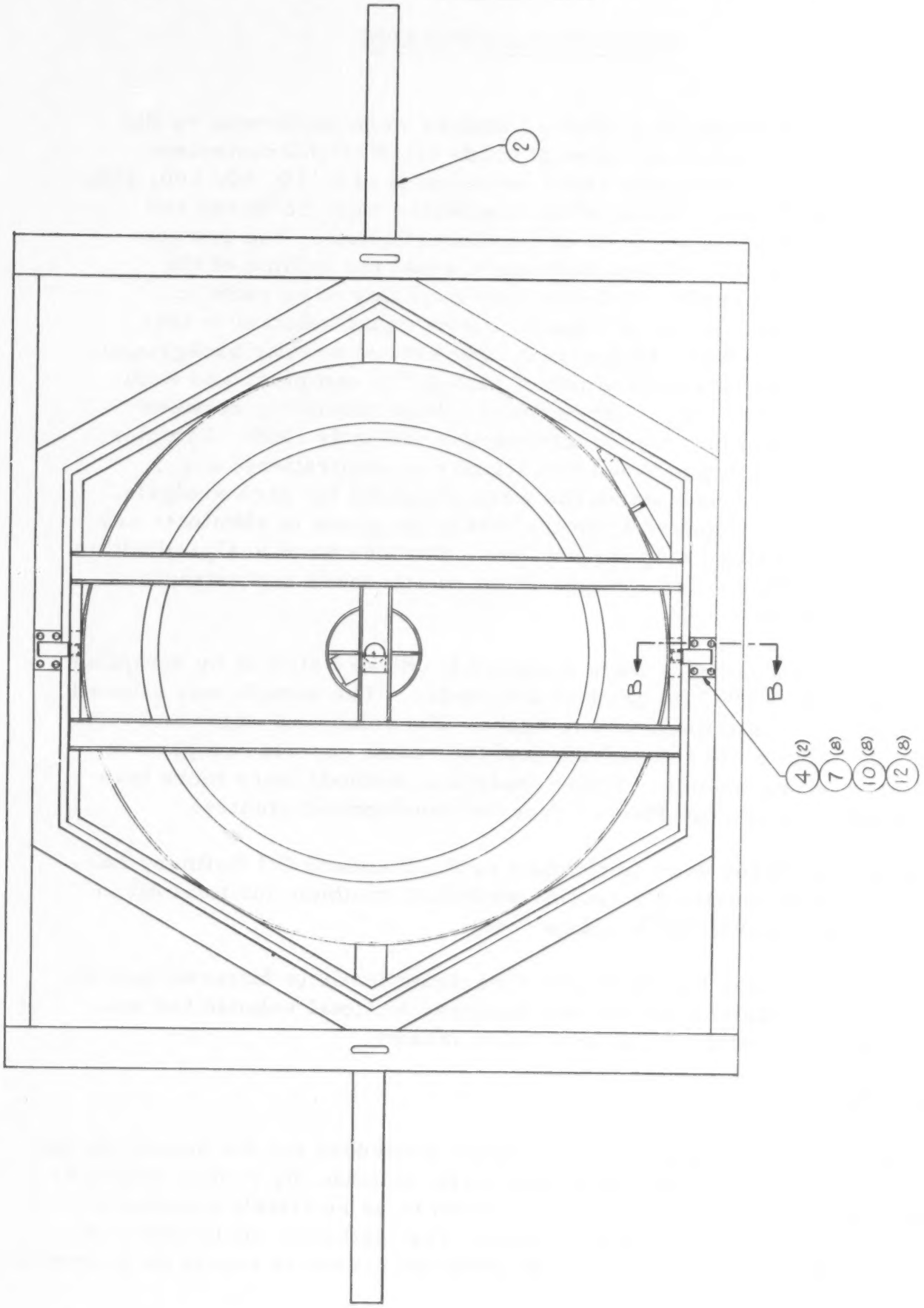
APPENDIX D. PHASE II SEPARATOR ASSEMBLY DRAWING 2



APPENDIX D. PHASE II SEPARATOR ASSEMBLY DRAWING 3



APPENDIX D. PHASE II SEPARATOR ASSEMBLY DRAWING 4



APPENDIX E

ANALYTICAL METHODS

Water effluent analyses in Phase I studies were performed by the Contractor. Standard samples of crude oil in trichloroethylene were prepared at concentrations (by volume) of 0, 10, 50, 100, 250, 500, and 1000 ppm. Water effluent samples were collected and extracted with three portions of trichloroethylene. The extracts were combined and volume made up to equal the volume of the original water sample. Colorimetric matching of extracts to known standards was done visually, using equal volumes in test tubes, viewed in white fluorescent light against a white background. Three to five observers compared each set of samples, and each set was compared two or three times. Reproducibility between observations and between observers was virtually 100%. Samples were rated as being between two standar concentrations; e.g., 50 - 100 ppm. Fresh standards were prepared for each analysis, using crude oil removed from the test in progress to eliminate any error due to aging, evaporation, etc. Samples were analyzed within two hours, since color changes occur in standards and extracts within 48 hours.

Recovered oil samples were analyzed in Phase I studies by sampling directly into a 1000 ml graduated cylinder. The sample was allowed to settle for a minimum of two hours. The volume of water and total sample volume were observed, and the result reported as percent water in oil by volume. These analytical methods were more than adequate to guide the Phase I process development studies.

Phase II analyses were performed by the Standard Oil Refinery Laboratory using Standard's routine analytical methods for total oil in water (ppm) and water in oil (percent).

Standard Oil uses the American Petroleum Institute Infrared Spectrophotometric Method for effluent analyses for total volatile and nonvolatile oil in water. The procedure follows:

SCOPE

This method describes a nonreference procedure for the determination of oily matter in water. It is especially suitable for routine monitoring of effluent streams which are known to be relatively constant as to the nature of oily matter present. The method is applicable over a wide range of concentrations. Calibration constants should be determined

for each type of oily matter encountered, and periodic recalibration is recommended.

OUTLINE OF METHOD

The oily matter is extracted from the water with carbon tetrachloride. The absorbance of the extract is determined with the use of an infrared spectometer and the oily matter concentration is claculated by means of Beer's Law.

DEFINITIONS

a) Absorbance
The logarithm to the base 10 of the ratio of radiant energy in a narrow spectral range incident on the sample to the radiant energy in the same range transmitted by the sample.

b) Absorptivity
An empirical coefficient based on the infrared absorption of the oil present in the sample per unit of oil concentration and sample thickness.

c) Oily Matter
Hydrocarbons, hydrocarbon derivatives, and all substances containing CH, CH_2, or CH_3 groups which show infrared absorption bands at 3.4 and 3.5 microns and are extractable from acidified water with carbon tetrachloride (CCl_4).

APPARATUS

a) Infrared Spectrometer
Any infrared spectrometer suitable for measuring absorbance in the 3.5 micron region.

b) Spectrophotometer Cells
Matched, 1 mm cells (NaCl), perferably with ground-glass stopper.

c) Glassware
Various pipettes and volumetric flasks, graduated cylinders, and 1 liter separatory funnels.

REAGENTS

Unless otherwise indicated, it is intended that all reagents conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society when such specifications are available; otherwise, use best available grade.

a) Hydrochloric Acid (Specific Gravity, 1.19).
b) Sodium Chloride, Crystals
c) Carbon Tetrachloride, Spectoscopic Grade

Individual bottles should be selected which have a low absorbance in the critical range.

SAMPLE

The general precautions governing the collection of all samples for oil determination should be observed. Whenever possible, the sample should be collected in the same calibrated container used for the extraction operation. Volume adjustment or transfer of sample is very likely to result in the loss of oil. Containers should be cleaned with carbon tetrachloride before use. If bottles are substituted for flasks, the screw caps should be lined with clean aluminum foil.

CALIBRATION STANDARDS

Weigh a quantity of the selected oil of known specific gravity into carbon tetrachloride and dilute to obtain a predetermined concentration, normally about 300 ppm by volume. Determine the total net absorbance as above and claculate the absorptivity constant K.

The oil used for calibration should be recovered, if feasible, from the water stream which is to be sampled. If this is impractical, an average absorptivity constant may be calculated from the absorptivities of various oils likely to be encountered in the refinery waste water.

An approximate calibration standard may be synthesized by blending 37.5 percent isooctane, 37.5 percent cetane, and 25 percent benzene. Experience has indicated that oils found in a typical refinery will not vary from the synthetic standard by more than $\pm$ 20 percent, except in the case of the low boiling aromatics, such as benzene, xylene, and cumene, which are essentially undetected.

PROCEDURE

a) Extraction
Transfer the entire sample (approx. three liters) into the extraction flask. Add 25 ml of concentrated HCl. Add 25 ml of CCl_4 to the sample bottle, rinse, and transfer contents into extraction flask. Turn on stirrer and extract for 20 minutes. Let the phase settle and repeat extraction with fresh 25 ml portions of CCl_4 the designated number of times (Note 1). Pass the CCl_4 portions through glass wool into an appropriate size volumetric flask (Note 1) and make up to volume.

Transfer the water sample from the extraction to a graduated cylinder, measure the volume, and subtract the volume of added HCl.

b) Infrared Determination
The absorbances of the sample extract and of the carbon tetrachloride blank are each determined or in a matched pair of cells.

Care should be taken to avoid spilling the sample extract on the cell while filling. To avoid leaving a film of oil on the ecterior, wipe the optical surfaces before each determination, first with lens tissue moistened with carbon tetrachloride, and then with dry lens tissue.

The spectometer is set to scan the spectrum in the region of the maximum absorption. These peaks occur in the vicinity of 3.42 microns and at exactly 3.50 microns. Net absorbances are determined by subtracting the absorption of the carbon tetrachloride blank from the sample absorption at these wave lengths. The sum of the two net absorbances is used in the calculations.

If the absorbance at either wave length of the original extract is greater than 1.0, make aliquot dilutions in carbon tetrachloride until the absorbances are between 0.2 and 1.0.

CALCULATION

Calculate the oily matter content of the water samples as follows:

$$C = \frac{(A) \times (S)}{(K) \times (W)} (F)$$

Where:

C = oily matter in parts per million by volume.

A = sum of the two net absorbances measured.

K = absorptivity, a constant developed during the calibration, and calculated as:

$$K = \frac{\text{sum of two measured net absorbances of calibration oil}}{\text{concentration of calibration oil in } CCl_4 \text{ in ppm}} \quad \text{(Note 3)}$$

S = volume of CCl_4 extract.

W = volume of water sample.

F = dilution of factor, calculated as

$$F = \frac{\text{Volume of diluted } CCl_4 \text{ extract}}{\text{volume of original } CCl_4 \text{ extract used to prepare the dilution}}$$

PRECISION, ACCURACY, AND SENSITIVITY

The results are reported to the nearest part per million. Precision is about ± 10 percent. Accuracy is about ± 10 percent if a representative calibration oil is used in obtaining the calibration constant, or about ± 20 percent with the use of synthetic calibration oil. Sensitivity is about 1 ppm.

REFERENCE

API Method 733-58

NOTES

Note 1. Use the following guide fro determining the number of carbon-tetrachloride extractions and the final volume to which the CCl_4 is to be adjusted.

Anticipated Oil Content (ppm)	Number of 25-ml CCl_4 Extractions	Final adjusted Volume Of CCl_4 mls
<20	1	50
>20	4	100

Note 2. Use 5 to 10 grams of crystalline Na Cl for drying the extract CCl_4 after having been made up to final volume.

Note 3. The K factor has been determined to be 0.042 for Pascagoula Refinery effluents.

The method used by the Standard Oil Refinery Laboratory to determine water in recovered crude oil was distillation with a water-immiscible solvent. The procedure used was ASTM designation D95-62 (Reapproved 1968); API Standard 2560. The method was adopted as a joint ASTM-API standard in 1967. It is the same as Method 3001 - Federal Test Method Standard No. 791.

APPENDIX F

SEPARATOR EFFICIENCY CALCULATIONS

Three parameters are useful in judging the performance of an oil/water separator. They are: 1) quality of water effluent, expressed in ppm oil content; 2) quality of recovered oil, expressed in percent water content; and, 3) percent of total influent oil recovered.

A materials balance equation provides the best method of determination of percent oil recovered, and also shows the effect of influent composition on this efficiency parameter. It is:

$$\text{Percent Oil Recovery} = 100 - \frac{\%\text{water in influent}}{\%\text{ oil in influent}} \times \frac{\text{ppm oil in water effluent}}{10^4}$$

For a separator producing a water effluent with 100 ppm oil, for instance, percent recovery for various influent compositions would be:

Influent % oil	% Recovery
0.1	90.01
1.0	99.01
5.0	99.81
10.0	99.91
50.0	99.99

On the other hand, a separator treating an influent with 10% oil at various effluent purity levels would achieve the following recoveries:

Ppm Oil in Effluent	% Recovery
10	99.991
100	99.91
500	99.55
1000	99.1
10000	91.0

APPENDIX G

PHASE II: SPECIFICATIONS OF OIL AND SALT WATER

Feed Inspections

APEC Separator Test 6/23/70 to 7/8/70

I. Specifications for Crude Used in Test:

Gravity, °API	-	31.6
Vis. @100°, SSU	-	53.86
Sulfur, Wt.%	-	0.374
RVP, ASTM D-323, PSI	-	2.8
Pour Pt., ASTM D-97, °F	-	+25
BS&W, %	-	1.0
Characterization Factor, UOPK	-	11.8
Aniline Point, °F (estimated)	-	190
ASTM Distillation, Method	-	D86
Start (5% on D-1160)	-	142/200
10	-	320/448
30	-	506/552
EP	-	552
% Rec.	-	40.0
% Res.	-	60.0

II. Refinery Effluent Where Test Water Was Drawn:

pH	-	7.7
Sulfides, ppm	-	Nil
Ammonia, ppm	-	8
Phenols, ppm	-	0.07
Dissolved 0_2, Mg/Liter	-	5.1
BOD, Mg/Liter	-	31
COD, Mg/Liter	-	102
Salt Content, %	-	0.8%